Hydraulic Models, Once You Have It – Exercise It

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Abstract

Hydraulic models are typically used to answer specific questions but not used to their full potential because of project scope or funding. Considering future possible uses during the model scoping/building phase can allow the models to be used to their full potential. How the Bonneville 2nd Powerhouse Forebay and The Dalles Forebay numerical models were used to evaluate the original design issues and then utilized to evaluate how project operations can influence fish passage success at the projects will be presented.

Introduction

Hydraulic models are used to visualize, to understand, and to explain hydraulic phenomenon in and around hydraulic structures. The Portland District relies heavily on physical models to evaluate and design proposed structural modifications on the Lower Columbia River Projects. Examples of such structures are the Bonneville 2nd Powerhouse Corner Collector, the Bonneville 2nd Powerhouse Fish Guidance Efficiency Program and The Dalles Spillwall. Another type of hydraulic model, three-dimensional computational fluid dynamics (CFD) models, has been added to the tool kit. CFD models have been in use for years but recent advancements in computer technology have made CFD and grid generation software commercially available. The CFD models are used to complement the physical models – but their strengths are different. In particular the CFD models automatically provide hydraulic data throughout the domain.

Typically a model study is initiated to address a specific question and analysis concentrates on the specific question. But the model provides additional data and rarely is that data fully probed. Visualization software has made great strides in the last few years and provides an excellent opportunity for the hydraulic engineer to visualize, to understand, and to explain hydraulic phenomenon.

Fish passage is a major issue in the Columbia River and significant dollars have been invested in building fish bypass structures that guide fish away from turbine routes of passage. The CFD model was exercised to look at forebay hydraulics beyond the turbine intakes. Two examples of CFD models (Bonneville 2nd Powerhouse Forebay and The Dalles Forebay) will be presented that show how the hydraulic phenomenon under different operating conditions might provide insight into fish guidance efficiencies at the projects.

Model Development and Initial Objectives

Pacific Northwest National Laboratory (PNNL) developed the Bonneville forebay CFD model (Rakowski, Richmond, Serkowski and Ebner, 2002). Bonneville 2nd Powerhouse has eight 66.5 MW (units 11 – 18) and two 13.1 MW fish turbine units with a total hydraulic capacity of 166,800 cfs. Fish turbine units are small turbines that supply water for the fish ladder attraction flows. At the time, the primary objective for developing the model was to evaluate lateral flow in the intakes to determine if a single vertical barrier screen design could be installed at all units, Figure 1. The vertical barrier screen had been designed assuming no lateral flow. Figure 1 illustrates the various components involved in screened bypass systems for juvenile fish passage. The juvenile fish enter the intake and encounter the submerged traveling screen and move up into the gate well slot. Once in the gate well slot the fish move up to the orifice and into the collection channel where they are routed around the turbines. The design was field tested in main unit 15 with good results. Concerns were raised that the lateral flows that exist under some operations would impact the effectiveness of the vertical barrier screen. The numerical model results showed that by the time the flow started to move up the gate slot to the vertical barrier screen the lateral flow component was negligible and one vertical barrier screen design could be applied at all units.

ENSR developed The Dalles forebay CFD model, (ENSR 2001). The Dalles Powerhouse consists of 22 turbine units and 2 fish turbine units with a total hydraulic capacity of 290,000 cfs. The primary objective was to evaluate the installation of J-Blocked Trashracks on the entire length of the powerhouse. The intent of the J-Blocked Trashracks was to block the upper part of the turbine intake and reduce the number of juvenile fish routed through the turbine. Since the model was developed, a prototype test showed that the J-Blocked Trashracks did not improve juvenile fish passage at The Dalles.

In both cases model development and validation followed the same process. Portland District gathered the drawings of all of the pertinent structural features and the bathymetry data. Portland District also gathered all of the validation data available, which was typically physical model data. PNNL or ENSR then built a single turbine model, which was validated against a previously constructed sectional physical model at Engineer Research and Development Center (ERDC), Figure 2. The single turbine model determined the necessary grid refinement. Once the single turbine model was validated against the sectional model the CFD model geometry, it could be duplicated to represent the powerhouse. The bathymetry information was used to create a grid of the forebay. The two grids were then coupled together. Validation of the full CFD model was done with physical model data and prototype data (if available), Figure 3.

Once the models were developed and validated the input files required to run the CFD models became the property of the Portland District. The district can operate the models with different boundary conditions (different operations) and make simple changes to the grids.

Exercising the Models

In the evaluation of the lateral flow at Bonneville 2nd Powerhouse 15 model runs were made, and resulted from a combination of 3 different operational scenarios and 2 structural alternatives. The 2 structural alternatives involved the deployment of Turbine Intake Extensions (TIEs) or the operations of the Ice and Trash Sluiceway. The structural alternatives had a minimum impact on the lateral flow in the intakes and appeared to have more of a local effect. The 3 different operational scenarios were: full powerhouse load (units 11 – 18), split end partial powerhouse load (units 11, 12, 17 and 18) and split middle partial powerhouse load (units 11, 14, 15 and 18). Although the different operations had a negligible impact on the lateral flow at the gate well slot and thus on the vertical barrier screen, the impact in the forebay is significant. The split partial powerhouse load is most representative of actual partial operations because of downstream attraction flow to the adult ladder entrances in the tailrace. Figure 4 shows the overall flow patterns developed for the 3 operational scenarios. Under both partial powerhouse loads flow patterns curve and dip near the face of the powerhouse. Figure 5 shows stream traces of particles released 10 feet below the water surface for the partial powerhouse load cases. The split end load case shows significantly more diving of the flow than the split middle. Is one of these partial load cases likely to provide better juvenile fish guidance? Intake fish screens only screen the upper part of the water column and fish near the floor of the intake will not be intercepted by the screen and thus will not be guided.

In 2002 spillway guidance efficiency at The Dalles was significantly different than previous years, approximately 44% of the juvenile fish used the spillway at 40% spill in 2002 and in previous years approximately 80% of the juvenile fish used the spillway at 40% spill. Was there a hydraulic component that may have contributed to this difference? In 2002 the powerhouse was operated differently, the powerhouse was blocked loaded to the west (units 1 through 7 were priority first on and last off). In previous years even units or odd units would be brought on line followed by odd or even units. Figure 6 represents streamlines at elevation 145 for a total river flow of 239,000 cfs and powerhouse operations that was west block loaded. Figure 7 represents streamlines at elevation 145 for the same flow conditions as shown in Figure 6 but with every other unit operating. In comparing Figures 6 and 7 some differences are noted but similar patterns exists in both figures. Figure 8 is a difference plot of velocity magnitude between Figure 6 and Figure 7. This highlights that this operational change has an impact all the way across the river. The hydraulic results do not explain the difference in spillway guidance efficiency but the information should be used to help design a biological test to evaluate the impact of this operational change.

Conclusions

Numerical hydraulic models provide an additional opportunity to evaluate, to understand and to explain hydraulic phenomenon in and around hydraulic structures for a wide range of operational scenarios and design alternatives. Visualization software facilitates the use of the model results and provides more insights into the significant changes in hydraulic conditions that result from changes in operations. Sometimes the best way to understand these impacts is through difference plots of hydraulic parameters. The numerical model data need to be studied and used to describe the hydraulic phenomenon and to design future data collection activities (in physical model or in the prototype).

References

ENSR, "Three-Dimension Computational Fluid Dynamics (CFD) Modeling of the Forebay of The Dalles Dam, Oregon," Final Report, DACW 3697-003-320, June 2001.

Rakowski, C. L., Richmond, M.C, Serkowski, J.A., and Ebner, L.L. (2002), "Three-Dimensional Simulation of Forebay and Turbine Intakes Flows for the Bonneville Project," HydroVision 2002, Portland, Oregon, July 2002.

Serkowski, J.A., Rakowski, C.L., and Ebner, L.L. (2002), "Visualization of Flow Patterns in the Bonneville 2nd Powerhouse Forebay," HydroVision 2002, Portland, Oregon, July 2002.

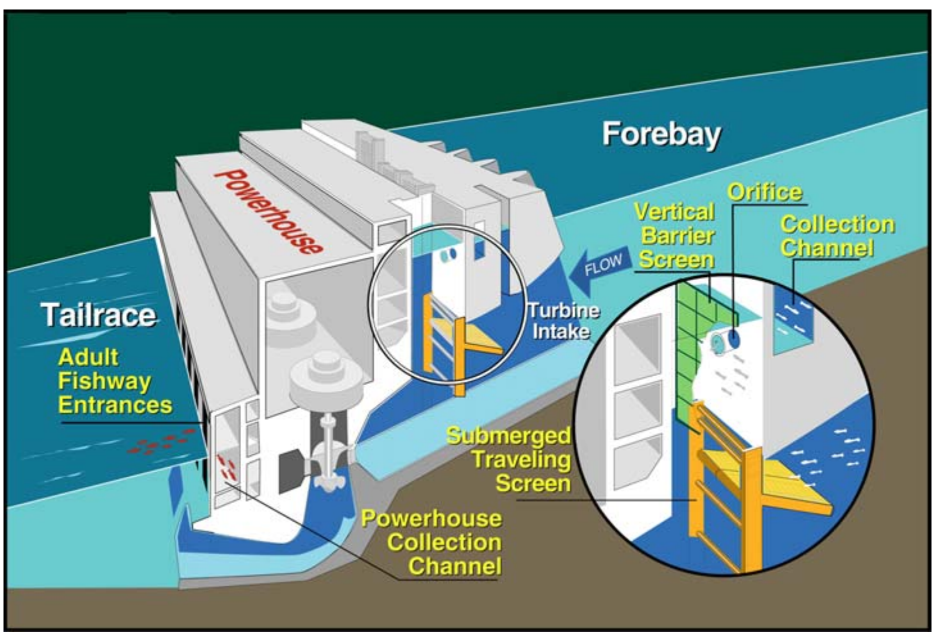

Figure 1. Schematic of Juvenile Fish Screen Bypass

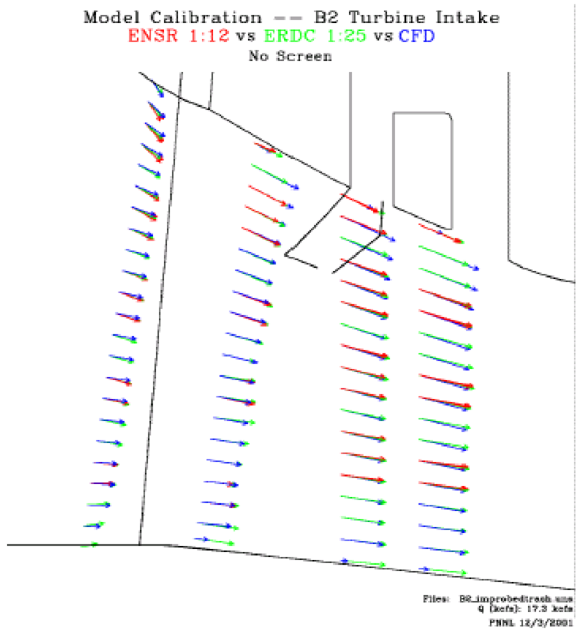

Figure 2. Bonneville 2nd Powerhouse Intake 17.3 Kcfs. Comparison of velocities from two physical models and the CFD model.

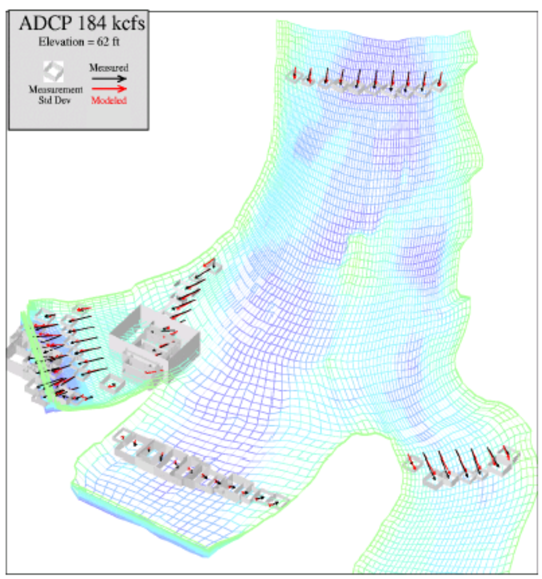

Figure 3. Comparison of CFD model and field-measured ADCP velocity measurements in the Bonneville Forebay. Boxes on the plot indicate the standard deviation of the field measurements.

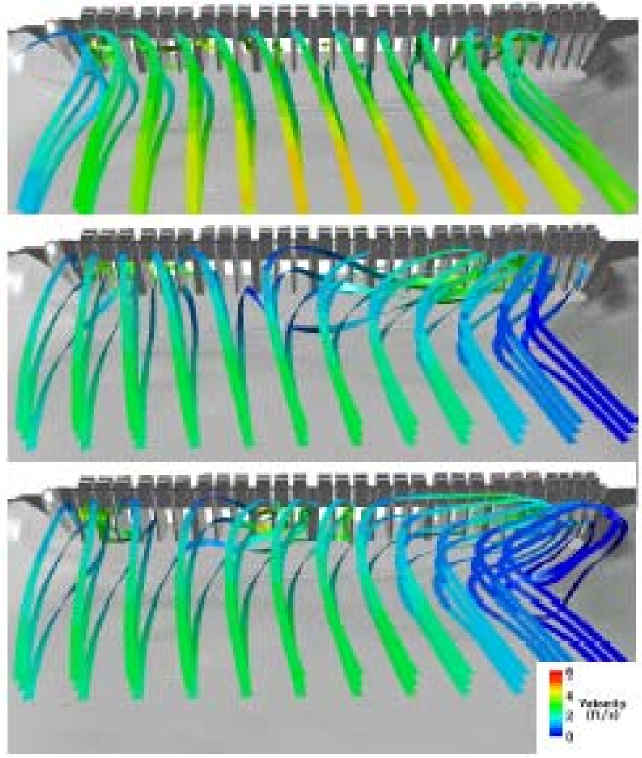

Figure 4. Bonneville 2nd Powerhouse - overall flow patterns resulting from full load (units 11 – 18), split end partial load (units 11, 12, 17 and 18) and split middle partial load (units 11, 14, 15, and 18); top to bottom respectively. Each unit operating at 16 Kcfs.

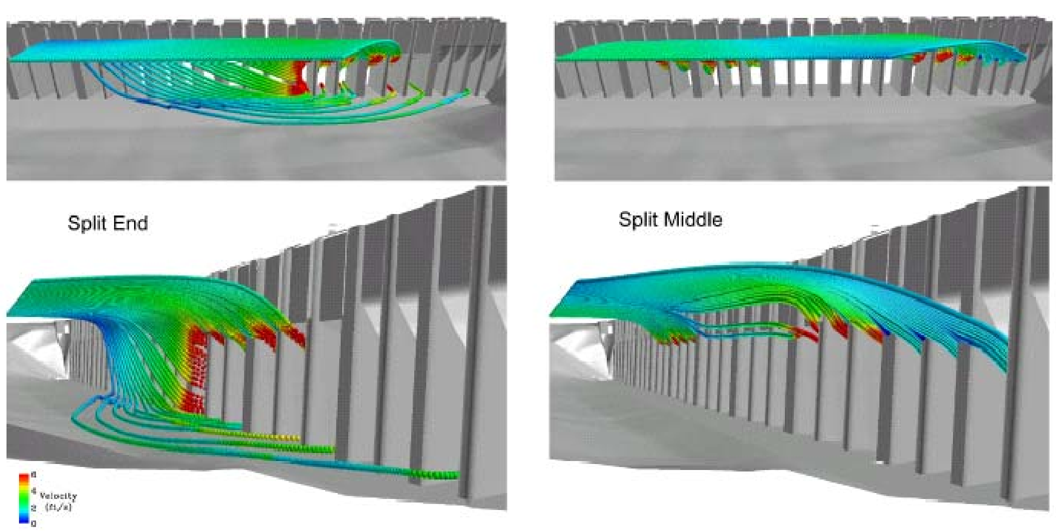

Figure 5. Bonneville 2nd Powerhouse - stream traces of particles released 10 feet below water surface for split end partial load (units 11, 12, 17 and 18) and split middle partial load (units 11, 14, 15 and 18). Each unit operating at 16 Kcfs.

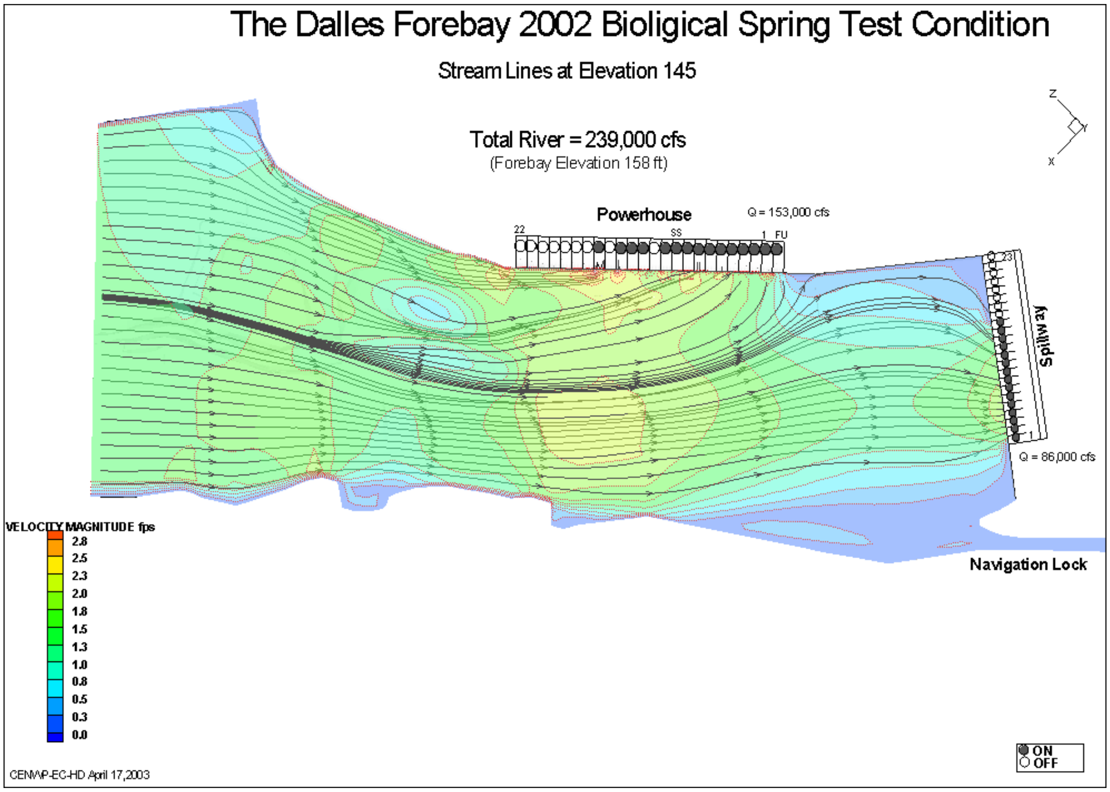

Figure 6. The Dalles 2002 Biological Test Condition, Blocked Loaded West End – streamlines at elevation 145.

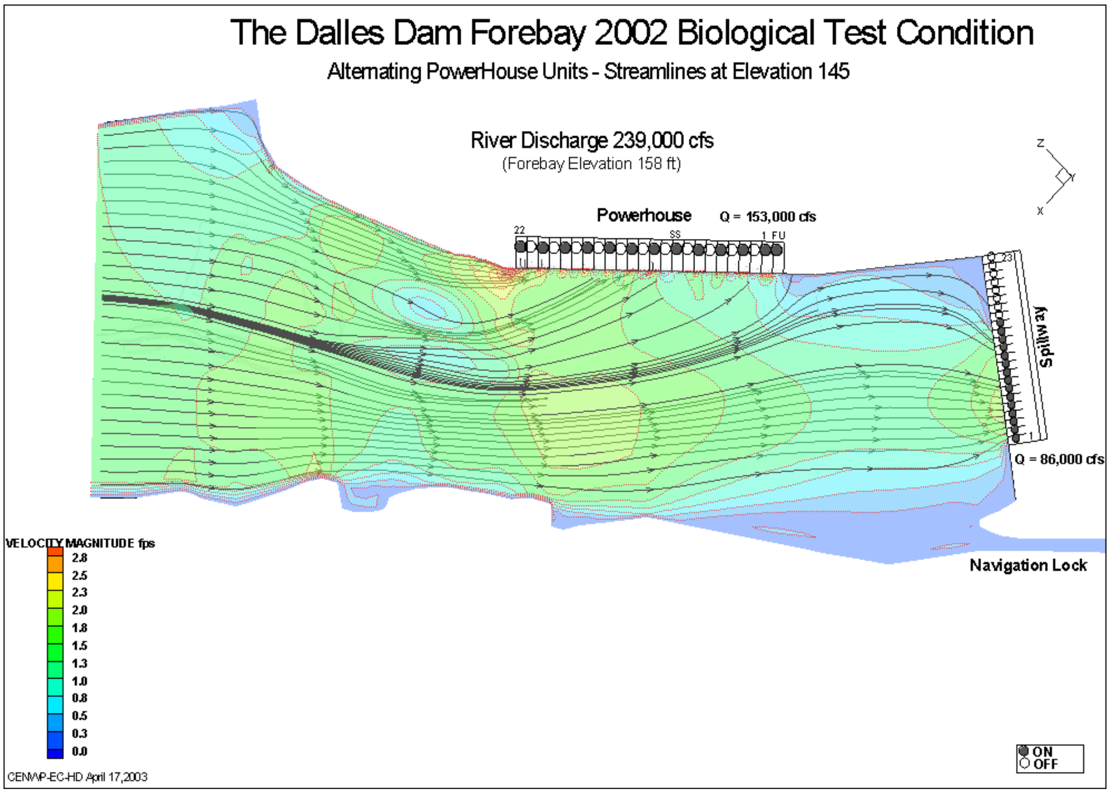

Figure 7. The Dalles 2002 Biological Test Condition, Alternatively Units – streamlines at elevation 145.

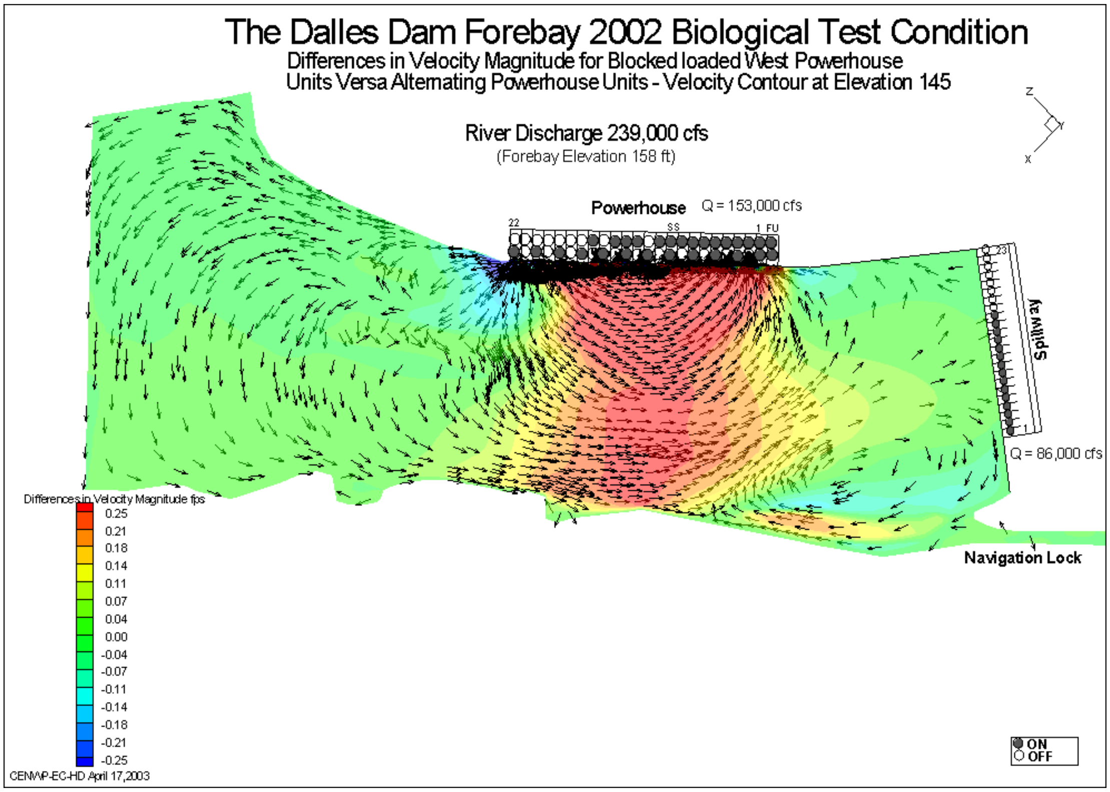

Figure 8. The Dalles 2002 Biological Test Condition, Difference in velocity magnitude at elevation 145 for Blocked Loaded West End minus Alternatively Units.